Title: **Creating a Water Quality Scale Methodology Using California as a Case Study**

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## Abstract

Water availability analysis has traditionally involved understanding how much water enters and leaves a region and how much is used or stored each year. This mass balance of water, or water budget, is useful for tracking *quantities* of water; however, it offers no insights into the *quality* of the water. This paper introduces a method for creating a water quality scale that utilizes unique categories for water quality and reserves additional categories for the insertion of local water quality data. The method is tested using California as a case study. A water quality scale applicable to California is created, and data for the city of Paso Robles is inserted to demonstrate the flexibility of the framework to be made location-specific. The resulting scale can be used by water resource engineers to compare different types of water in terms of quality, measure both the quantity and quality of a local water supply simultaneously, and evaluate the most sustainable water supply options available. Furthermore, the scale can be customized for use anywhere in the world.

## Introduction

### Mass Balance

A mass balance, based on the law of conservation of mass, accounts for all of the material entering and leaving a system. The reconciliation of mass flows in a balance, allowing flows that are unknown or difficult to measure directly to be estimated, since mass cannot disappear or be created spontaneously.

The concept of a mass balance is applied to water as a means of accounting for the water that enters, leaves, and is stored in a city or watershed, in countries all over the world (Vardon et al. 2007, Karimi et al. 2013, Momblanch et al. 2014, Escriva-Bou et al. 2020).

**Water Budgets in California**

In California, a mass balance, when applied to water, is referred to as a water budget. Water budgets are produced at various scales. Every 4-5 years, the State of California's Department of Water Resources publishes water budgets at the hydrologic unit (watershed) and state-wide levels (State of California 2019a) and cities publish water budgets at the local level. The water budgets are published in tabular form and list the quantities of water available from each source (*e.g*., groundwater, surface water) and quantities of water used by category (*e.g*., urban, agriculture).

California uses water budgets to better understand the differences in supply and use in wet and dry years, plan for future needs, and move toward water resource sustainability (State of California 2019b). California has been, and will continue to be, a useful example of extremes brought on by a wide variety of climates and terrains (State of California 2019b).

While water budgets are useful for tracking water quantities, they do not provide information about the quality of the water. To add water quality to the quantities of water in a water budget, there must be a way to define varying levels of water quality, such as through a scale for water quality.

**Existing Water Quality Scales**

Examples of existing water quality scales can be found in both the academic literature and in practice. Some measure single contaminants (*e.g., E. coli* or salinity) across a wide range of water types, while others focus on a single water type (*e.g.,* reclaimed or graywater) but measure quality across multiple parameters. However, no water quality scale can be found in literature that assesses a comprehensive range of parameters across the full range of water types.

In a recent paper, Lundy et al. (2017) develop a single-parameter scale for allowable *E. coli* concentrations across a wide range of water types, from potable water (0 cfu/100ml) to irrigation water (1000 cfu/100ml). Salinity is commonly measured as a single parameter scale of water quality and ranges from fresh water (0-0.5 ppt or g/L) to briny water (50 ppt or g/L).

Abdul Azis et al. (2018) develop a multiple-tier scale for recreational contact with coastal water in Colombia. The contaminants included in the scale are total coliform, fecal coliform, biochemical oxygen demand (BOD), total suspended solids (TSS), ammonium, nitrates, and soluble phosphorus. The scale features low, medium, high, and very high contaminant levels, where high is the maximum allowable, and very high exceeds the allowed contaminant level.

Multi-tiered scales for water quality also exist for reclaimed water, which is municipal wastewater that has been treated to meet specific water quality criteria, and are used to judge when this water can be used for a range of purposes (US EPA 2012). The Food and Agriculture Organization (Ayers and Westcot 1985) provides recommendations for agricultural irrigation, and the U.S. Environmental Protection Agency (EPA) and the U.S. Agency for International Development (AID) (US EPA 2012) list water quality requirements for turf grass irrigation using reclaimed water. Both these agencies organize water quality requirements into three tiers of increasing water use restrictions: the highest tier is for crops and turf that are sensitive to salts, the middle tier is for plants that can handle some salinity, and the lowest tier is for crops and grasses with good levels of tolerance for salt. The water quality parameters used in these scales include salinity, electrical conductivity, total dissolved solids, ion toxicity, sodium, chloride, boron, and pH. The state of Texas also has a multi-tiered scale for reclaimed water in which one tier is appropriate if human contact with the reclaimed water is likely and the other is appropriate if human contact is not likely (TECQ 2019). The water quality parameters include enterococci, fecal coliform or *Escherichia coli*, carbonaceous biochemical oxygen demand (CBOD) or BOD, and turbidity.

Several tiered scales for water quality exist for graywater, usually defined as all wastewater generated in households or office buildings from streams without fecal contamination. However, wastewater from kitchen sinks and dishwashers is excluded from the definition of graywater in California (HSC 2019). The National Sanitation Foundation, now known as NSF International, and the American National Standard Institute (ANSI), developed the NSF/ANSI Standard 350 for Onsite Residential and Commercial Water Reuse Treatment Systems. They have categorized their water quality scales according to source, i.e., residential (R) and commercial (C) wastewater. The water quality parameters include CBOD, TSS, turbidity, *Escherichia coli*, pH, storage vessel disinfection, color, odor, oily film and foam, and energy consumption.

The review of existing water quality scales includes examples of single and multi-tiered scales that group levels of water quality into categories. However, there is no scale of water quality that contains a comprehensive number of the types of water found in the natural environment that can be used for urban and agricultural purposes. The purpose of this work is to provide a methodology to create a water quality scale that can be used to add water quality to a water budget.

## Methods and Data

We propose an eight step method that can be used to create a water quality scale that includes water found in both natural and built environments for use anywhere in the world. California is used as a case study to demonstrate the methodology. The method is described in the detail below and summarized in Figure 1.

**Step 1: Select a Geographical Context**

Because water quality standards vary by location, the first step in creating a water quality scale is to select the geographical context in which the scale is intended to be used.

If the scale is intended for global use, international standards can be used. However, since drinking water standards can vary from country to country, for example, the scale will have more credibility and applicability if local standards are used. Therefore, to demonstrate the methodology for creating a water quality scale, the state of California is used as a case study for two reasons: intermittent water scarcity and transparent data.

From 2012 to 2016, California endured an unprecedented multi-year drought that threatened the water supplies of communities and residents (USGS 2019a). The drought also decreased agricultural production in many areas; worsened groundwater overdraft and subsidence, with associated impacts on essential water, transportation, and other utility infrastructure; and harmed fish, wildlife, and ecosystems (State of California 2019a). It ended as the result of record-breaking rainfall, which drew attention to the vulnerability of California's aging flood and water management infrastructure and fragile ecosystems (State of California 2019a). A consequence of California's history of drought is that water resources in California are well monitored. Water quantity and quality data are available for most streams, rivers, lakes, and groundwater basins in the state. While sampling and measurements are usually done locally, the results are deposited into a state-wide database that is accessible to the public (SWRCB 2019d).

**Step 1: Select a Geographic Context**
Water quality standards vary by location. If the scale is intended for global use, international standards can be used. However, since drinking water standards can vary from country to country, for example, the scale will have more credibility and applicability if local standards are used.

| | |
|---|---|
| **Step 2: Collect Regulatory Water Quality Standards**<br>State, federal, and international regulatory bodies set water quality parameter limits for common or dangerous pollutants to protect human health and ecosystems. Site-specific standards are set if there is a particular species to protect, for example, so the standards most "local" to the location selected are collected in this step. | See **Table 1** for an example. |
| **Step 3: Collect Water Quality Data for Water Found or Used in the Selected Location**<br>Water quality parameter data is collected to identify expected general values or ranges of contaminants in water, such as urban stormwater, raw sewage, graywater, primary treated wastewater, secondary treated wastewater, and tertiary treated wastewater. | See **Table 2** for an example. |
| **Step 4: Compile Water Quality Parameters**<br>Create a matrix with types of water listed in rows and water quality parameters in columns. Populate the center of the matrix with the corresponding water quality limits and values collected. Apply a color-coding system to allow the values to be easily identified as maximum, average, or minimum levels. | See **Figures 2 & 3** for an example. |
| **Step 5: Characterize Water Quality Parameters**<br>At the simplest level, water quality can be described and measured by its bacteriological, physical, chemical and radiological characteristics, so the minimum number of parameters representing each characteristic of water are identified in this step. The reasons for the selections are explained in Figure 3, which also shows the parameters and units of measure grouped by characteristics. | See **Figure 4** for an example. |
| **Step 6: Document Data Sources and Notes**<br>Once the water quality parameters have been reduced to a manageable number, the data sources and notes are documented in an identical, but separate, table to the one created in Step 4, with types of water listed in rows and water quality parameters listed in the columns. The center of the matrix is populated with the data source references for the values inserted into the aforementioned table. | See **Figures 5 & 6** for an example. |
| **Step 7: Order Water Quality Parameters**<br>This step involves grouping parameters by characteristics, then ordering the groups in an intuitive way to make the scale easy to understand and the water quality parameters grouped within a characteristic easy to compare. | See **Figure 4** for an example. |
| **Step 8: Order Categories of Water Quality**<br>The water quality parameters are ordered from water with the lowest concentration of pollutants to water with the highest level of contamination. When comparing water quality parameter values for two separate rows, if some parameters are higher for one row than for another row, and other values for that row are lower than they are for the other row, a selection criteria is applied to determine which row should be placed higher on the scale, depending on the objectives or purpose of the resulting scale. Blank categories are included as place holders for water with quality that varies by location so that they are not left out of the water quantity analysis. | See **Table 3** for an example. |

Figure 1. Summary of the Water Quality Scale Methodology

Once a geographical context has been selected, the next step involves collecting water quality standards published by regulatory agencies specific to that location.

**Step 2: Collect Regulatory Water Quality Standards**

Water quality standards define how clean water needs to be for a given use, such as potable water, irrigation water, and livestock drinking water. They also need to consider uses of, and standards for, reclaimed water, harvested rainwater, and graywater.

State, federal and international regulatory bodies set water quality parameter limits for common or dangerous pollutants to protect human health and ecosystems. Consequently, the allowable levels of pollutants vary by water use. Site-specific standards are set if there is a particular species to protect, for example, so the standards most "local" to the location selected should be collected in this step. Guidelines can be used when standards are not available or applicable. Some standards are updated often, so the most recent versions should be collected.

For the state of California, the documents that provide water quality standards applicable to potable water, reclaimed water uses, irrigation water, livestock drinking water, harvested rainwater, graywater reuse, brackish water, and seawater are listed in Table 1.

**Step 3: Collect Water Quality Data for Water Found or Used in the Selected Location**

Water quality ranges describe the quality of "used" water or water found in the natural environment. Water quality parameter data sets reported in the academic literature should be collected in this step to identify expected general values or ranges of contaminants in water, such as urban stormwater, raw sewage, graywater, primary treated wastewater, secondary treated wastewater, and tertiary treated wastewater. For California, water quality parameters for all of the types of water are listed in Table 2.

Table 1. Applicable Regulatory Water Quality Standards Collected for California

| | | Bibliography Reference | Water Types Addressed by the Document |
|---|---|---|---|
| **Standards Authored by California State Government Agencies** | Water Quality Control Plan for the Central Coast Basin, June 2019 Edition | CCRWQCB 2019a | Agricultural Irrigation Water, Livestock Drinking Water |
| | California Regulations Related to Drinking Water, April 16, 2019 | SWRCB 2019a | Potable Drinking Water |
| | Maximum Contaminant Levels and Regulatory Dates for Drinking Water, U.S. EPA vs California, October 2018 | SWRCB 2018a | Potable Drinking Water |
| | Regulations Related to Recycled Water, October 2018 | SWRCB 2018b | Potable Surface Water and Groundwater Augmentation |
| | 2016 California Plumbing Code, Chapter 16 | CPC 2016 | Captured Rainwater for Indoor Use and Outdoor Use |
| | California Ocean Plan, 2015 | SWRCB 2015 | Seawater |
| **Standards Authored by U.S. Federal Government Agencies** | National Primary Drinking Water Regulations | US EPA 2009 | Potable Drinking Water |
| **Guidelines Authored by U.S. Federal Government Agencies** | National Secondary Drinking Water Regulations | US EPA 2019 | Potable Drinking Water |
| | 2017 Potable Reuse Compendium | US EPA 2017 | Potable Surface Water and Groundwater Augmentation |
| | 2012 Guidelines for Water Reuse | US EPA 2012 | Potable Surface Water and Groundwater Augmentation, Graywater Reuse, Industrial Reuse, Municipal Reuse, Environmental Reuse, Crop Irrigation Water |
| | Desalting Handbook for Planners, 3rd Edition, July 2003 | USDI 2003 | Brackish Water, Seawater |
| **Guidelines Authored by International Organizations** | Water Quality for Agriculture | Ayers and Westcot 1985 | Agricultural Irrigation Water |

Table 2. Water Quality Category Definitions and Sources

| | Categories of Water Quality | Definitions |
|---|---|---|
| **Potable Water** | Potable Drinking Water | Water that meets California Regulations and US EPA drinking water standards. |
| | Potable Surface Water & Groundwater Augmentation | Augmentation of a drinking water source (surface or groundwater) with reclaimed water followed by an environmental buffer that precedes normal drinking water treatment (US EPA 2012). |
| **Reclaimed Water** | Public Park Irrigation Water & Recreational Impoundments | The use of reclaimed water for non-potable applications in municipal settings where public access is not restricted (US EPA 2012). The use of reclaimed water in an impoundment in which no limitations are imposed on body-contact water recreation activities (US EPA 2012). |
| | Restricted Contact Impoundments | The use of reclaimed water in an impoundment where body contact is restricted (US EPA 2012). |
| | Restricted Contact Municipal Reuse | The use of reclaimed water for non-potable applications in municipal settings where public access is controlled or restricted by physical or institutional barriers, such as fencing, advisory signage, or temporal access restriction (US EPA 2012). |
| | Environmental Reuse | The use of reclaimed water to create, enhance, sustain, or augment water bodies, including wetlands, aquatic habitats, and stream flow (US EPA 2012). |
| **Stormwater** | Captured Rainwater for Indoor Use | Captured rainwater used for urinal/toilet flushing, clothes washing, trap priming, cooling tower make-up water, large-scale spray irrigation, or ornamental fountains and other water features (CPC 2016). |
| | Captured Rainwater for Outdoor Use | Captured rainwater used for car washing; surface, subsurface or drip irrigation; and small-scale spray irrigation (CPC 2016). |
| | Urban Stormwater | Untreated rainwater runoff that has come in contact with the urban environment. |
| **Agricultural Water** | Livestock Drinking Water | Meets 2012 Guidelines for Water Reuse for concentrations of substances in livestock drinking water (US EPA 2012). |
| | Food Crop Irrigation Water | The use of reclaimed water to irrigate food crops that are intended for human consumption (US EPA 2012). |
| | Non-food Crop Irrigation Water | The use of reclaimed water to irrigate crops that are not consumed by humans (US EPA 2012). |
| | Processed Food Crop Irrigation Water | The use of reclaimed water to irrigate crops that are processed before human consumption (US EPA 2012). |
| | Agricultural Irrigation Water | Meets the United Nations Food and Agriculture Organization's Guidelines for Interpretations of Water Quality for Irrigation (Ayers and Westcot 1985). |
| **Graywater** | Commercial Graywater Reuse | Treated graywater for multi-family or commercial restricted indoor and unrestricted outdoor use (US EPA 2012). |
| | Residential Graywater Reuse | Treated graywater for residential restricted indoor and unrestricted outdoor use (US EPA 2012). |
| | Graywater from Washing Clothes | Untreated laundry wash water. |
| | Graywater from Bathroom Sink & Shower | Untreated wastewater from a bathroom sink and/or shower/bathtub. |
| **Industrial Water** | Industrial Reuse | The use of reclaimed water for industrial applications and facilities, power production, and extraction of fossil fuels (US EPA 2012). |
| | Conventional Oil Produced Water | Water transferred from geologic formations to the surface during fossil fuel production (Meng et al. 2016). |
| **Wastewater** | Tertiary Treated Wastewater | Secondary treated wastewater that has been through some type of physicochemical treatment such as coagulation, filtration, or reverse osmosis and additional disinfection (Pepper et al. 2015). |
| | Secondary Treated Wastewater | Primary treated wastewater that has been through biological treatment such as a trickling filter bed, an aeration tank, or a sewage lagoon and a disinfection step (Maier et al. 2009). |
| | Primary Treated Wastewater | Wastewater that has gone through a settling process to separate floating material and heavy solids from liquid waste. |
| | Raw Sewage | Untreated refuse liquids or waste matter usually carried off by sewers. |
| **Saltwater** | Brackish Water | Water that has a higher salinity than freshwater and a lower salinity than seawater. |
| | Seawater | Salt water in or from the sea. |
| **Local Water** | Raw Precipitation | Local untreated precipitation (rain or snow). |
| | Raw Surface Water | Existing local untreated surface water. |
| | Raw Groundwater | Existing local untreated groundwater. |
| | Stored or Other Water Supply | Water stored in tanks or other supplies of water such as piped or transported water from outside the area. |

**Step 4: Compile Water Quality Parameters**

Using a table, spreadsheet, or database, create a matrix with the types of water listed in rows, and water quality parameters in columns. Populate the center of the matrix with the corresponding water quality limits and values collected during steps 2 and 3, as depicted in Figure 2.

Some of the values collected and inserted into the matrix will represent maximum levels of contamination, others will represent averages, and some, as in the case of disinfectants, will represent minimum levels required. Applying a color-coding system allows the values to be easily identified as being at maximum, average, or minimum levels.

For the California-specific data, red highlighting is used to indicate values representing a Maximum Contaminant Level (MCL). MCLs are enforceable standards set by the EPA or California's Environmental Protection Agency (CalEPA). Orange highlighting indicates that the value represents an average. Yellow highlighting indicates that the value is a minimum concentration level. Single values that are not highlighted are unenforceable maximum levels of contamination. A range of values means that the level of concentration of the given contaminant is expected to fall within the range listed. Figure 3 summarizes this data format and color-coding system.

**Step 5: Characterize Water Quality Parameters**

Some types of water, such as potable drinking water, have around one hundred parameters that define its quality (SWRCB 2018a). A scale with that many water quality parameters would be impractical in practice. For this reason, a water quality parameter selection process is used to reduce the number of parameters while still adequately representing its quality.

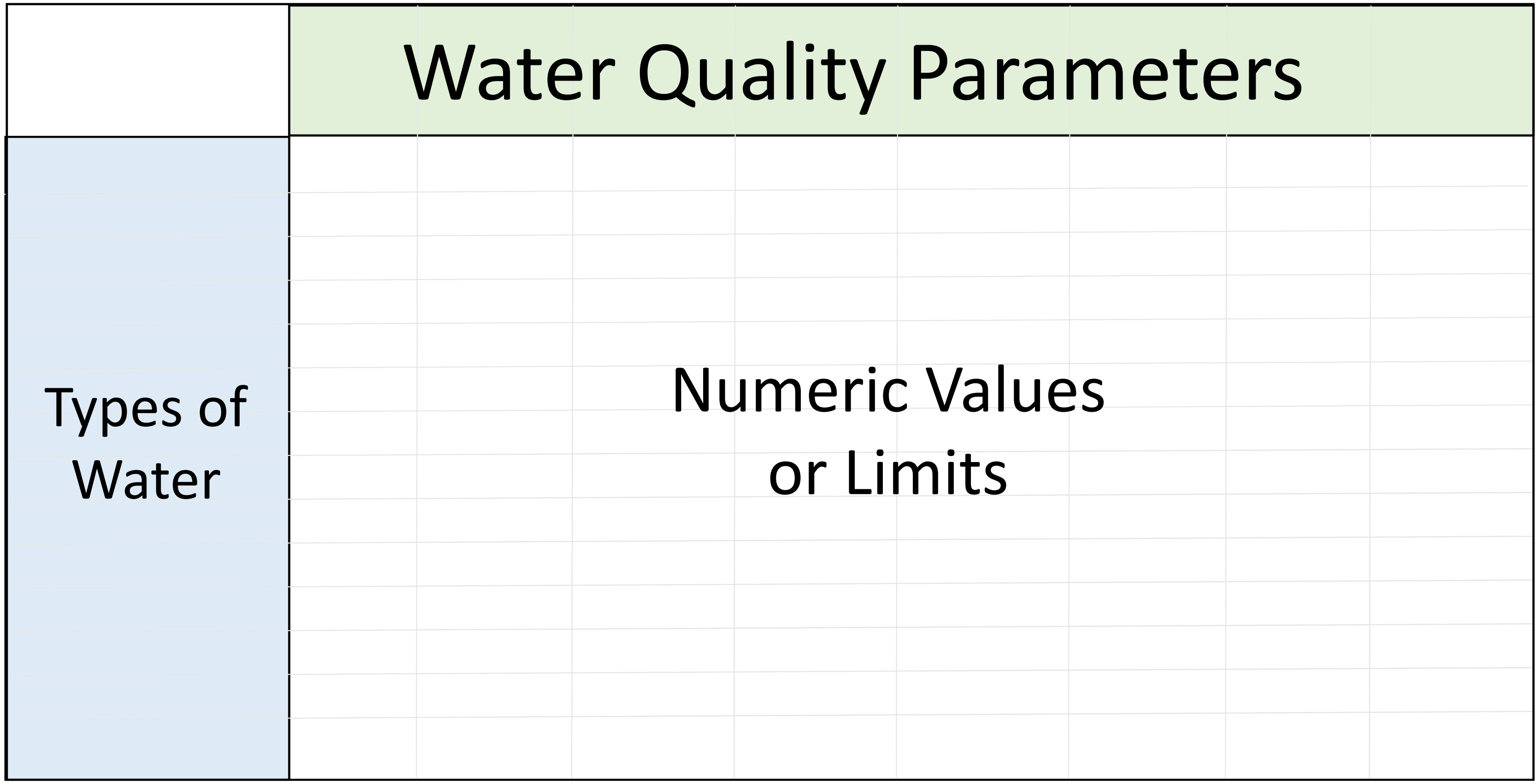


Figure 2. Conceptual depiction of matrix listing types of water, water quality parameters, and corresponding numeric values or limits.

| Data Format | Example | Definition |
|---|---|---|
| Single value | 30 | Value represents a maximum level of contamination, unless highlighted in orange or yellow. |
| Range of values | 50–300 | Level of concentration varies within the range of values listed. |
| Red highlighting | 15 | Enforceable maximum set by a regulatory agency, referred to as a Maximum Contaminant Level (MCL). |
| Orange highlighting | 200 | Value represents an average, rather than a maximum or minimum. |
| Yellow highlighting | 1 | Value represents the required minimum concentration level. |

Figure 3. Water Quality Scale Data Format and Color Code

Since, at the simplest level, water quality can be described and measured by its bacteriological, physical, chemical and radiological characteristics, the minimum number of parameters representing each characteristic of water are identified in this step.

Water quality standards do not require the same water quality parameters to be tested and measured for each type of water. For some types of water, standards require that bacteriological quality be measured using *E. coli*, whereas, for other types of water, fecal coliform is measured. For this reason, multiple bacteriological parameters are needed. Similarly, disinfectant standards for some types of water require that chorine residual be measured, whereas the standards for other types of water require that total chorine be measured. This step reduces the total number of water quality parameters to just those needed for each characteristic in order to depict the quality of the water accurately.

For California, 23 water quality parameters are needed to describe the bacteriological, physical, chemical, and radiological water quality characteristics of the water in each category. Some parameters have been selected because they are common contaminants found in water in California, for example, or because they measure levels of disinfectants. The reasons for the selections are provided in Figure 4, which also included the parameters and units of measure, grouped by characteristic.

**Step 6: Document Data Sources and Notes**

Now that the water quality parameters have been reduced to a manageable number, around 20 to 25, in the last step, the data sources and notes should be documented in a separate, but identical, table to the one created in Step 4, in which the types of water should be listed in rows, and water quality parameters should be listed in the columns. However, instead of replicating the last table, populate the center of the matrix with the data source reference for each value inserted into the

**Bacteriological** - By including these three water quality parameters, the bacteriological quality of almost every type of water in the scale is captured, based on the water quality limits and data available.

**Physical** - By including these three water quality parameters, the physical quality of almost every type of water in the scale is captured, based on the water quality limits and data available.

**Principal Contaminants in California** – These water quality parameters were included in the scale because they are the eight most common contaminants detected in community drinking water wells at levels above the maximum contaminant level (MCL) (SWRCB 2013). On the scale, these principal contaminants are grouped into organic and inorganic chemicals, two of which are also radiological water quality parameters.

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Water Quality Parameters | | | | | | | | | | | | | | | | | | | | | | |
| | Bacteriological | | | Physical | | | | Chemical | | | | | | | | | | | | | | Disinfectants | |
| | | | | | | Salinity | | Oxygen Demand | | | | | Principal Contaminants in California | | | | | | | | | | |
| | | | | | | | | | | | | | Inorganic Chemicals | | | | | | Organic Chemicals | | | | |
| | | | | | | | | | | | | | Radiological | | | | | | | | | | |
| **Full Name** | **Fecal Coliform** | **Total Coliform** | ***Escherichia coli*** | **Turbidity** | **Total Suspended Solids** | **Total Dissolved Solids** | **Sodium** | **Total Organic Carbon** | **Biochemical Oxygen Demand** | **Carbonaceous Biochemical Oxygen Demand** | **Oil & Grease** | **pH** | **Gross Alpha Particle Activity** | **Uranium** | **Total Nitrogen** | **Nitrate as Nitrogen** | **Arsenic** | **Perchlorate** | **Tetrachloroethylene** | **Trichloroethylene** | **1,2-Dibromo-3-chloropropane** | **Chlorine Residual** | **Total Chlorine** |
| **Abreviation** | | | *E. coli* | | TSS | TDS | | TOC | BOD | CBOD | | | | | | | | | PCE | TCE | DBCP | | |
| **Units** | (CFU/100 ml) | (CFU/100ml) | (CFU/100ml) | (NTU) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | | (pCi/L) | (pCi/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) |

**Salinity** is important for tracking salts in irrigation water to prevent crop damage and reduced yields (Ayers and Westcot 1985). Salt and Nutrient Management Plans are being developed for every groundwater basin in California (SWRCB 2020). Desalination is used in California, both in coastal areas to reduce the salinity of seawater and inland to reduce the salinity of brackish water. Consequently, Sodium was added to the scale to track salinity along with TDS.

**Oxygen Demand** - Both BOD and CBOD are used as indications of the effectiveness of pollutant removal in the wastewater treatment process. TOC is sometimes used as a quick and accurate alternative to the more lengthy BOD analysis. Since treated wastewater is used in California in the form of reclaimed water, these three water quality parameters were included in the scale since together they cover most types of water listed in the scale.

**Oil & Grease** is included as one of the key parameters for describing the quality of urban runoff (Horner 1994).

**Disinfectants** - Chlorine Residual and Total Chlorine are included in the scale to track the levels of disinfectants present in the water. For potable drinking water, this is a maximum level, because too much chlorine is damaging to human health (CDC 2019). For other categories, a minimum level is shown on the scale since a minimum amount of chlorine is required to protect against recontamination during distribution and storage (CDC 2019).

Figure 4. Explanation of Water Quality Parameter Selection for a Scale of Water Quality in California

aforementioned table. Include any notes regarding the numeric values, such as "7-day median." Figures 5 and 6 document the data source(s) for each water quality parameter value, including notes, for California.

**Step 7: Order Water Quality Parameters**

This step involves grouping parameters by characteristic and then ordering the groups in an intuitive way to make the scale easy to understand and the water quality parameters in each characteristic easy to compare.

For California, the order for the water quality parameters is depicted in Figure 4. The bacteriological parameters are listed first, followed by the physical parameters, the chemical parameters, and lastly the disinfectants.

The bacteriological parameters are listed first because an exceedance in *E. coli* or fecal coliform indicates the presence of human pathogens. The physical parameters are listed next. These characteristics are placed together because the parameters in both groups give an indication of water treatment system effectiveness, which is important for human health. The physical and chemical groups of parameters are hinged together by the parameters that measure salinity, so the chemical parameters are listed next. Within the chemical parameters, there are two groups: oxygen demand, and principal contaminants in California. The oxygen demand parameters serve a purpose similar to those of the bacteriological and physical parameters, in that they indicate water treatment effectiveness. Hence, they are listed near the bacteriological and physical parameters. Oil and grease and pH are listed next so that the principal contaminants, the only remaining chemical parameters, are grouped together. There are eight principal contaminants in California that have been selected, but they are represented by nine parameters since both Nitrate as Nitrogen and Total Nitrogen

| # | Categories of Water Quality | Fecal Coliform | Total Coliform | *E. coli* | Turbidity | TSS | TDS |
|---|---|---|---|---|---|---|---|
| 1 | Potable Drinking Water | (SWRCB 2019a) | | (SWRCB 2019a) | (SWRCB 2019a) | | (US EPA 2019) & (SWRCB 2019a) |
| 2 | Potable Surface Water & Groundwater Augmentation | | 7-day med, 240 (max) (SWRCB 2018b) & (US EPA 2012, table 4-16) | | avg for media filters, 10 NTU (max) (US EPA 2017, table 7-1) & (US EPA 2012, table 4.4) | | |
| 3 | Tertiary Treated Wastewater | | | | | (Bulloch et al. 2015) | |
| 4 | Food Crop Irrigation Water | non detect (7-day median), 14 (max) (US EPA 2012, table 4.4) | 7-day med, 240 (max) (US EPA 2012, table 4.9) | | avg for media filters, 10 NTU (max) (US EPA 2012, tables 4.4 & 4.9) | | |
| 5 | Public Park Irrigation Water & Recreational Impoundments | | 7-day med, 240 (max) (US EPA 2012, table 4.7) | | avg for media filters, 10 NTU (max) (US EPA 2012, table 4.4 & 4.7) | | |
| 6 | Commercial Graywater Reuse | | | test average, single-sample max 200 (US EPA 2012, table 2.5) | test average, single-sample max 5 (US EPA 2012, table 2.5) | test average, single sample max 30 (US EPA 2012, table 2.5) | |
| 7 | Residential Graywater Reuse | | | test average, single-sample max 240 (US EPA 2012, table 2.5) | test average, single-sample max 10 (US EPA 2012, table 2.5) | | |
| 8 | Industrial Reuse | 7-day median, 800 (max) (US EPA 2012, table 4.4) | 7-day med, 240 (max) (US EPA 2012, table 4.14) | | avg for media filters, 10 NTU (max) (US EPA 2012, table 4.14) | (US EPA 2012, table 4.4) | |
| 9 | Restricted Contact Impoundments | | 7-day med (US EPA 2012, table 4.12) | | | | |
| 10 | Non-food Crop Irrigation Water | | (US EPA 2012, table 3.6) | | | | |
| 11 | Restricted Contact Municipal Reuse | | 7-day med, 240 (max) (US EPA 2012, table 4-8) | | | | |
| 12 | Processed Food Crop Irrigation Water | | | | | | |
| 13 | Environmental Reuse | | | | | | |
| 14 | Secondary Treated Wastewater | | | | | (Bulloch et al. 2015) | |
| 15 | Agricultural Irrigation Water | | | | | | (US EPA 2012, table 3.4) & (Ayers and Westcot 1985) |
| 17 | Captured Rainwater for Indoor Use | | | (CPC 2016) | | | |
| 18 | Captured Rainwater for Outdoor Use | | | | Minimum Treatment Requirement: Debris excluder or other approved means in compliance with Section 1602.9.10 or 100 microns in compliance with Section 1602.9.11. (CPC 2016) | | |
| 19 | Graywater from Washing Clothes | (De Gisi et al. 2016) | | | (De Gisi et al. 2016) | | |
| 20 | Graywater from Bathroom Sink & Shower | | | | | | |
| 21 | Primary Treated Wastewater | (Boczek et al. 2010) | | (Boczek et al. 2010) | | | |
| 22 | Raw Sewage | (Lowe et al. 2009) | | (Lowe et al. 2009) | | (Lowe et al. 2009) | |
| 23 | Brackish Water | | | | | | (USDI 2003) |
| 24 | Seawater | | | | | | (USDI 2003) |
| 25 | Conventional Oil Produced Water | | | | | | (Echchelh et al. 2018) |
| 26 | Urban Stormwater | | | | | (Pitt et al. 2018) | |

Figure 5. Bacteriological and Physical Water Quality Parameter Data Sources

| | Categories of Water Quality | Sodium | TOC | BOD | CBOD | Oil & Grease | pH | Gross Alpha Particle Activity | Uranium | Total Nitrogen | Nitrate as Nitrogen | Arsenic | Perchlorate | PCE | TCE | DBCP | Chlorine Residual | Total Chlorine |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Potable Drinking Water | | | | | | (US EPA 2019) | (SWRCB 2019a) & (SWRCB 2018a) | (SWRCB 2018a) | | (SWRCB 2019a) | (SWRCB 2019a) & (SWRCB 2018a) | | (SWRCB 2018a) | | (US EPA 2009) | (US EPA 2019) & (SWRCB 2019a) | |
| 2 | Potable Surface Water & Groundwater Augmentation | | (SWRCB 2018b) & (US EPA 2012, table 4-16) | | | | (US EPA 2017, table 7-1) & (US EPA 2012, table 4.4) | | | ave of 4 consecutive samples (SWRCB 2018b) & (US EPA 2017, table 3-2) & (US EPA 2012, table 4-16) | | | | | | | (US EPA 2017, table 7-1) & (US EPA 2012, table 4.4) | |
| 3 | Tertiary Treated Wastewater | | (Bulloch et al. 2015) | | | | (Bulloch et al. 2015) | | | | | | | | | | (Bulloch et al. 2015) | |
| 4 | Food Crop Irrigation Water | | | 5-day BOD test (US EPA 2012, table 4.4) | | | (US EPA 2012, table 4.4) | | | | | (US EPA 2012, table 3.5) | | | | | (US EPA 2012, table 4.4) | |
| 5 | Public Park Irrigation Water & Recreational Impoundments | | | | | | | | | | | | | | | | | |
| 6 | Commercial Graywater Reuse | | | | test average, single sample max 25 (US EPA 2012, table 2.5) | | (US EPA 2012, table 2.5) | | | | | | | | | | | (US EPA 2012, table 2.5) |
| 7 | Residential Graywater Reuse | | | | | | | | | | | | | | | | | |
| 8 | Industrial Reuse | | | 5-day BOD test (US EPA 2012, table 4.4) | | | (US EPA 2012, table 4.4) | | | | | | | | | | (US EPA 2012, table 4.4) | |
| 9 | Restricted Contact Impoundments | | | | | | | | | | | | | | | | | |
| 10 | Non-food Crop Irrigation Water | | | | | | (US EPA 2012, table 4.4) | | | | | (US EPA 2012, table 3.5) | | | | | | |
| 11 | Restricted Contact Municipal Reuse | | | | | | | | | | | | | | | | | |
| 12 | Processed Food Crop Irrigation Water | | | | | | | | | | | (US EPA 2012, table 3.5) | | | | | | |
| 13 | Environmental Reuse | | | | | | | | | | | | | | | | | |
| 14 | Secondary Treated Wastewater | | (Bulloch et al. 2015) | | | | (Bulloch et al. 2015) | | | | | | | | | | (Bulloch et al. 2015) | |
| 15 | Agricultural Irrigation Water | (CCRWQB 2019a) | | | | | (US EPA 2012, table 3.4) & (Ayers and Westcot 1985) | | | | (US EPA 2012, table 3.4) & (Ayers and Westcot 1985) | (CCRWQB 2019a) | | | | | | |
| 16 | Livestock Drinking Water | short-term exposure max 4000 (US EPA 2012, table 3.7) | | | | | | | | | (CCRWQCB 2017) | (US EPA 2012, table 3.7) & (CCRWQB 2019a) | | | | | | |
| 19 | Graywater from Washing Clothes | | | (De Gisi et al. 2016) | | | (De Gisi et al. 2016) | | | (De Gisi et al. 2016) | | | | | | | | |
| 20 | Graywater from Bathroom Sink & Shower | | | | | | | | | | | | | | | | | |
| 21 | Primary Treated Wastewater | | (Boczek et al. 2010) | | | | (Boczek et al. 2010) | | | | | | | | | | | |
| 22 | Raw Sewage | | (Lowe et al. 2009) | | (Lowe et al. 2009) | | | | | (Lowe et al. 2009) | | | | | | | | |
| 24 | Seawater | (Duxbury et al. 2019) | | | | | (Marion et al. 2011) | | | | | (SWRCB 2015) | | | | | | |
| 25 | Conventional Oil Produced Water | (Echchelh et al. 2018) | | | | (Echchelh et al. 2018) | | | | | | | | | | | | |
| 26 | Urban Stormwater | | | | | (Pitt et al. 2018) | | | | | | | | | | | | |

Figure 6. Disinfectants and Chemical Water Quality Parameter Data Sources

measure Nitrogen levels. The remaining parameters are those related to disinfectant levels, so they are listed last.

**Step 8: Order Categories of Water Quality**

To formulate a scale of water quality, the rows of water quality parameters are ordered from water with the lowest concentration of pollutants to water with the highest level of contamination.

When comparing water quality parameter values for two separate rows, if some parameters for a row are higher than they are for the other row, and it has other parameters that are lower than they are for the other row, then a selection criteria is applied to determine which row should be ordered before the other, depending on the objectives or purpose of the resulting scale. For California, bacteriological and disinfectant parameters have a higher priority when ordering the rows. A detailed explanation of the ordering of the categories utilizing this priority selection criteria is described in Table 3.

Once the rows are ordered, rows with identical parameter values can be combined together. These rows are now the defined categories for water quality. Types of water with identical water quality requirements are grouped together to form a single water quality category. Types of water with unique water quality requirements are shown on the scale as individual categories for water quality.

Blank categories are included as place holders for water quality that varies by location, such as the quality of surface water, groundwater, precipitation, and other sources of stored water or a local supply, so that they are not left out of the water quantity analysis.

## Results and Discussion

Table 3. Explanation for Scale Ordering of the Water Quality Categories

| | **Categories of Water Quality** | **Explanation for Position on Scale** |
|---|---|---|
| **1** | Potable Drinking Water | Category 1 water has the lowest level of contamination for each water quality parameter on the scale compared to all of the other categories. |
| **2** | Potable Surface Water & Groundwater Augmentation | Category 2 water can have higher turbidity levels (2 NTU) than category 1 (1 NTU). |
| **3** | Tertiary Treated Wastewater | Category 3 water can have higher TOC levels (3 - 3.1 mg/L) than category 2 (0.5 mg/L). |
| **4** | Food Crop Irrigation Water | Category 4 water can have higher BOD levels (10 mg/L) than category 3 (2.2 - 2.6 mg/L). |
| **5** | Public Park Irrigation Water & Recreational Impoundments | Categories 4 and 5 have similar levels of water quality, except that category 4 water cannot have more than 0.1 mg/L of arsenic in it, and category 5 has no arsenic restrictions. Consequently, category 5 is placed after category 4. |
| **6** | Commercial Graywater Reuse | Categories 6 and 7 both have lower TSS concentrations that category 8, so they are ordered before category 8. Category 7 water can have higher *E. coli* levels (14 CFU/100ml) than category 6 (2.2 CFU/100ml), and higher turbidity levels (5 NTU) than category 6 (2 NTU), so category 6 is placed before category 7. |
| **7** | Residential Graywater Reuse | |
| **8** | Industrial Reuse | Category 8 water can have higher TSS (30 mg/L) than category 7 (10 mg/L). |
| **9** | Restricted Contact Impoundments | Categories 8 and 9 are almost identical, except that category 8 has a turbidity maximum of 2 NTU, and category 9 has no turbidity restrictions. Since category 8 is more restrictive than category 9, category 9 is placed after category 8. |
| **10** | Non-Food Crop Irrigation Water | Category 10 water can have higher total coliform levels (23 CFU/100 ml) than category 9 (2.2 CFU/100 ml). |
| **11** | Restricted Contact Municipal Reuse | Categories 10 and 11 have similar levels of water quality, except that category 10 water cannot have more than 0.1 mg/L of arsenic in it, and category 11 has no arsenic restrictions. Consequently, category 11 is placed after category 10. |
| **12** | Processed Food Crop Irrigation Water | Categories 11 and 12 are similar, except that category 11 has a total coliform average of 23 CFU/100 ml, and category 12 has no total coliform restrictions. |
| **13** | Environmental Reuse | Category 13 is similar to category 12, but does not have a pH range or arsenic limit, so it is placed below category 12. |
| **14** | Secondary Treated Wastewater | Category 14 water has a 0.5 mg/L chlorine residual level, which is a lower level of water quality than all of the categories above. |
| **15** | Agricultural Irrigation Water | Category 15 is the first category without a chlorine level requirement, so it is placed after categories 1-14. |
| **16** | Livestock Drinking Water | Category 16 does not have a chorine requirement either, but has higher levels of contaminants allowed for all parameters, compared to category 15, so it is placed after category 15. |
| **17** | Captured Rainwater for Indoor Use | Category 17 has fewer water quality requirements than category 16, so it is placed after category 15. |
| **18** | Captured Rainwater for Outdoor Use | Category 18 has the same source as category 17, but no water quality parameter requirements, as specified in the standard, so it is placed after category 17. |
| **19** | Graywater from Clothes Washing | Categories 19 through 22 are ordered by the upper end of the range for each of the three bacteriological water quality parameters, *E. coli*, fecal coliform, and total coliform. |
| **20** | Graywater from Bathroom Sink & Shower | |
| **21** | Primary Treated Wastewater | |
| **22** | Raw Sewage | |
| **23** | Brackish Water | Categories 23 through 25 are ordered by the level of TDS in each of those three categories of water quality. |
| **24** | Seawater | |
| **25** | Conventional Oil Produced Water | |
| **26** | Urban Stormwater | Category 26 has the highest upper range of TSS, oil & grease, and pH, so it is ordered last on the scale. |
| **A** | Raw Groundwater | Categories A through D were placed at the bottom of the scale as placeholders for local water quality values to be inserted. |
| **B** | Raw Surface Water | |
| **C** | Raw Precipitation | |
| **D** | Stored or Other Water Supply | |

The result is an original water quality scale for use in California, shown in Figure 7, which defines 26 different categories of water quality. Each category on the scale is identified by a number and title to describe the type of water it represents. Table 2 lists the definitions and their sources for each category of water quality included in the scale. The levels of water quality are represented by 23 water quality parameters describing bacteriological, physical, chemical, and radiological water quality characteristics. An explanation for the selection of the parameters is given in Figure 3. Figures 5 and 6 document the data source(s) and include notes for each water quality parameter value associated with each category of water in the scale. The categories of water quality listed in the scale are ordered from highest quality to lowest quality, with an explanation of the order given in Table 3. The values on the scale that are MCLs are highlighted red. Average values are highlighted orange. Values intended to be a minimum allowable level are highlighted in yellow (Figure 3). Alpha categories (A, B, C, and so on) act as placeholders for the water quality parameter values for the local supply of water to be inserted, including groundwater, surface water, and precipitation.

The method and resulting scale can be used by water managers and engineers in five ways to:

1. Compare the quality of different types of water.
2. Customize the scale with local water quality data.
3. Measure the quantity and quality of the local water supply simultaneously.
4. Communicate the sustainability of the water supply options available.
5. Examine water quality anywhere in the world, with this starting point.

These five applications of the water quality scale are described in the next five sections.

**1. Compare the Quality of Different Types of Water**

| | | Water Quality Parameters | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Bacteriological | | | Physical | | | | Chemical | | | | | | | | | | | | | | Disinfectants | |
| | | | | | | | Salinity | | | | | | | Principal Contaminants in California | | | | | | | | | | |
| | | | | | | | | | Oxyen Demand | | | | | Inorganic Chemicals | | | | | | Organic Chemicals | | | | |
| | | | | | | | | | | | | | | Radiological | | | | | | | | | | |
| | Categories of Water Quality | Fecal Coliform (CFU/100ml) | Total Coliform (CFU/100ml) | *E. coli* (CFU/100 ml) | Turbidity (NTU) | TSS (mg/L) | TDS (mg/L) | Sodium (mg/L) | TOC (mg/L) | BOD (mg/L) | CBOD (mg/L) | Oil & Grease (mg/L) | pH | Gross Alpha Particle Activity (pCi/L) | Uranium (pCi/L) | Total Nitrogen (mg/L) | Nitrate as Nitrogen (mg/L) | Arsenic (mg/L) | Perchlorate (mg/L) | PCE (mg/L) | TCE (mg/L) | DBCP (mg/L) | Chlorine Residual (mg/L) | Total Chlorine (mg/L) |
| 1 | Potable Drinking Water | 0 | | 0 | 1 | | $1x10^3$ | | | | | | 6.5-8.5 | 15 | 20 | | 10 | 0.01 | 0.006 | 0.005 | 0.005 | 0.0002 | 0.2 4 | |
| 2 | Potable Surface Water & Groundwater Augmentation | | 2.2 | | 2 | | | | 0.5 | | | | 6.5-8.5 | | | 10 | | | | | | | 1 | |
| 3 | Tertiary Treated Wastewater | | | | | 0.9 | | | 3-3.1 | 2.2-2.6 | | | 7.1-7.4 | | | | | | | | | | 2.7-3.4 | |
| 4 | Food Crop Irrigation Water | 0 | 2.2 | | 2 | | | | | 10 | | | 6-9 | | | | | 0.1 | | | | | 1 | |
| 5 | Public Park Irrigation Water & Recreational Impoundments | 0 | 2.2 | | 2 | | | | | 10 | | | 6-9 | | | | | | | | | | 1 | |
| 6 | Commercial Graywater Reuse | | | 2.2 | 2 | 10 | | | | | 10 | | 6-9 | | | | | | | | | | | 0.5- 2.5 |
| 7 | Residential Graywater Reuse | | | 14 | 5 | 10 | | | | | 10 | | 6-9 | | | | | | | | | | | 0.5- 2.5 |
| 8 | Industrial Reuse | 200 | 2.2 | | 2 | 30 | | | | 30 | | | 6-9 | | | | | | | | | | 1 | |
| 9 | Restricted Contact Impoundments | 200 | 2.2 | | | 30 | | | | 30 | | | | | | | | | | | | | 1 | |
| 10 | Non-Food Crop Irrigation Water | 200 | 23 | | | 30 | | | | 30 | | | 6-9 | | | | | 0.1 | | | | | 1 | |
| 11 | Restricted Contact Municipal Reuse | 200 | 23 | | | 30 | | | | 30 | | | 6-9 | | | | | | | | | | 1 | |
| 12 | Processed Food Crop Irrigation Water | 200 | | | | 30 | | | | 30 | | | 6-9 | | | | | 0.1 | | | | | 1 | |
| 13 | Environmental Reuse | 200 | | | | 30 | | | | 30 | | | | | | | | | | | | | 1 | |
| 14 | Secondary Treated Wastewater | | | | | 6.9-13 | | | 1.2 | 5.1-5.7 | | | 7.2-7.9 | | | | | | | | | | 1 | |
| 15 | Agricultural Irrigation Water | | | | | | $2x10^3$ | 9 | | | | | 6.5-8.4 | | | | 5-30 | 0.1 | | | | | | |
| 16 | Livestock Drinking Water | | | | | | | $1x10^3$ | | | | | | | | | 100 | 0.2 | | | | | | |
| 17 | Captured Rainwater for Indoor Use | | | 100 | 10 | | | | | | | | | | | | | | | | | | | |
| 18 | Captured Rainwater for Outdoor Use | | | | | | | | | | | | | | | | | | | | | | | |
| 19 | Graywater from Clothes Washing | $50–1.4×10^3$ | $200.5–7×10^5$ | | 50–444 | 68–465 | | | | 48–472 | $231-2.9x10^3$ | | 7.1–10 | | | 1–40 | | | | | | | | |
| 20 | Graywater from Bathroom Sink & Shower | $0–3.4×10^5$ | $10–2.4×10^7$ | | 44–375 | 7–505 | | | | 50–300 | 100-633 | | 6.4–8.1 | | | 3–19 | | | | | | MCL | | |
| 21 | Primary Treated Wastewater | $7.14x10^6 - 1.58x10^7$ | | $2.18x10^6 - 7.90x10^6$ | 26-55 | 43-75 | | | 16-37 | | | | 6.3-7.2 | | | | | | | | | Avg. | | |
| 22 | Raw Sewage | $1x10^4-1.73x10^8$ | | $1.0x10^4-8.16x10^7$ | | $22-1.69x10^3$ | | | 35-738 | | $112-1.1x10^3$ | 10-109 | 6.4-10.1 | | | 20-85 | 0.2-8.5 | | | | | Min. | | |
| 23 | Brackish Water | | | | | | $1x10^3-3.5x10^4$ | | | | | | | | | | | | | | | | | |
| 24 | Seawater | | | | | | $3.5x10^4$ | $1.1x10^4$ | | | | | 7.4-9.6 | | | | | 0.003 | | | | | | |
| 25 | Conventional Oil Produced Water | | | | | | $80-4.72x10^5$ | $1.2x10^5$ | | | | 0.565 | 4.3-10 | | | | | | | | | | | |
| 26 | Urban Stormwater | | | | | $0.11-4.8x10^3$ | | | | | | $0.060-2.9x10^3$ | 3.4-10.7 | | | | | | | | | | | |
| A | Raw Groundwater | | | | | | | | | | | | | | | | | | | | | | | |
| B | Raw Surface Water | | | | | | | | | | | | | | | | | | | | | | | |
| C | Raw Precipitation | | | | | | | | | | | | | | | | | | | | | | | |
| D | Stored or Other Water Supply | | | | | | | | | | | | | | | | | | | | | | | |

Figure 7. Scale of Water Quality Parameter Categories for Water in California. The values on the scale that represent a Maximum Contaminant Level (MCL) are highlighted red. Average values are highlighted orange. Values intended to be a minimum allowable level are highlighted in yellow.

The scale is useful for comparing the different types of water in California to one another. Since the scale is ordered in descending levels of quality, it acts as a pictorial reminder of how the different categories of water compare to one another.

The water quality parameter data allows water managers to identify how much cleaner one category is from another and perhaps identify whether or not it is appropriate to substitute one type of water for another in times of scarcity.

**2. Customize the Scale with Local Water Quality Data**

The scale is also useful for comparing the quality of the available water supply in a particular location once the local water quality parameter data have been inserted into the lettered categories (A, B, C, and so on) at the bottom of the scale and moved up among the numbered water quality categories for direct comparisons.

This process is undertaken by inserting water quality parameter values for:

1. Local groundwater into category A.

    For multiple sources of groundwater, insert additional categories for each unique source at the bottom of the list of categories, for example, under E or F.

2. Local surface water into category B.

    For more than one surface water body in the given location, insert an additional category (G, H, I, and so forth) for each surface water body.

3. Local precipitation into category C.

    For any captured or stored precipitation with a different set of water quality data values, an additional category is added (I, J, K. and so on).

4. Any other sources of local water supply into category D.

For water that is transported to the local area by pipeline or other stored water not already included as a category, a new category is added for each additional source (K, L, M. and so forth).

If the water quality parameter data for any category of water known to be present is unavailable, the category remains as part of the scale, even though will be left blank, so that it is not forgotten in the water budget of available water.

Once the water quality parameter values that describe the quality of the local water sources have been inserted into the appropriate categories on the scale (A, B, C, and so on), the rows for the categories labeled with a letter can be moved up into the upper, numbered portion of the scale to appropriate locations. Each location should be chosen in such a manner that the category above the inserted category has a higher level of water quality and the category below has a lower level of water quality.

### *2.1 Example of the Scale in Use*

To demonstrate the scale in use, water quality parameter data for the City of El Paso de Robles, California (hereafter referred to as Paso Robles) have been inserted into the scale.

#### *2.1.1 Application of the Scale to the City of Paso Robles, California*

Paso Robles is located on the Central Coast of California in San Luis Obispo County. It has a population of over 30,000 people and an area of almost 20 square miles (Paso Robles 2019a).

Paso Robles used over 6 million cubic meters (5,153 acre-feet) of water in 2015, but the city projects that by 2045, when the city expects to reach “buildout,” it will use over 11 million cubic meters (9,519 acre-feet) per year (AFY) (Paso Robles 2016), an 85% increase in water use over a span of 30 years. With such a large increase in water demand expected, the city will need to make the most of the water it has available.

*2.1.2 Quantification of Water Entering or Found within the Paso Robles City Limit Boundary*

To characterize the water that Paso Robles has available, water quality data for these local supplies, which are detailed below, are inserted into the blank categories at the bottom of the scale, as shown in Figure 8.

For Paso Robles, water in the local environment includes:

1. *Groundwater* from one groundwater basin only, namely, the Paso Robles Groundwater Basin, also known as Basin No. 3-4.06, according to the California Department of Water Resources (Paso Robles 2016). USGS water quality parameter data for this basin is inserted into category A in Figure 8 (USGS 2019b).
2. One *surface water* body, i.e., the Salinas River (Paso Robles 2016). Central Coast Ambient Monitoring Program water quality parameter data for the Salinas River is inserted into category B in Figure 8 (CCRWQCB 2019b).
3. *Raw precipitation.* The average annual rainfall in Paso Robles is about 14 inches (Paso Robles 2019b). The rainwater that infiltrates the ground before coming into contact with urban areas is accounted for in category C. Since water quality parameter data is not available, category C in Figure 8 will not be filled in, but it will act as a placeholder for the quantity of precipitation when it is compared to other water categories in Figure 9.

Additional sources of water for Paso Robles include:

1. *Four water storage tanks* that augment the water supply, when needed (Paso Robles 2016). Water quality parameter data published by the city of Paso Robles is inserted into category D in Figure 8 (Paso Robles 2018).

| | | Water Quality Parameters | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Bacteriological | | | Physical | | Chemical | | | | | | | | | | | | | | | | Disinfectants | |
| | | | | | | | Salinity | | Oxyen Demand | | | | | Principal Contaminants in California | | | | | | | | | | |
| | | | | | | | | | | | | | | Inorganic Chemicals | | | | | | Organic Chemicals | | | | |
| | | | | | | | | | | | | | | Radiological | | | | | | | | | | |
| | Categories of Water Quality | Fecal Coliform (CFU/100ml) | Total Coliform (CFU/100ml) | *E. coli* (CFU/100 ml) | Turbidity (NTU) | TSS (mg/L) | TDS (mg/L) | Sodium (mg/L) | TOC (mg/L) | BOD (mg/L) | CBOD (mg/L) | Oil & Grease (mg/L) | pH | Gross Alpha Particle Activity (pCi/L) | Uranium (pCi/L) | Total Nitrogen (mg/L) | Nitrate as Nitrogen (mg/L) | Arsenic (mg/L) | Perchlorate (mg/L) | PCE (mg/L) | TCE (mg/L) | DBCP (mg/L) | Chlorine Residual (mg/L) | Total Chlorine (mg/L) |
| 1 | Potable Drinking Water | 0 | | 0 | 1 | | $1x10^3$ | | | | | | 6.5-8.5 | 15 | 20 | | 10 | 0.01 | 0.006 | 0.005 | 0.005 | 0.0002 | 0.2 4 | |
| 2 | Potable Surface Water & Groundwater Augmentation | | 2.2 | | 2 | | | | 0.5 | | | | 6.5-8.5 | | | 10 | | | | | | | 1 | |
| 3 | Tertiary Treated Wastewater | | | | | 0.9 | | | 3-3.1 | 2.2-2.6 | | | 7.1-7.4 | | | | | | | | | | 2.7-3.4 | |
| 4 | Food Crop Irrigation Water | 0 | 2.2 | | 2 | | | | | 10 | | | 6-9 | | | | | 0.1 | | | | | 1 | |
| 5 | Public Park Irrigation Water & Recreational Impoundments | 0 | 2.2 | | 2 | | | | | 10 | | | 6-9 | | | | | | | | | | 1 | |
| 6 | Commercial Graywater Reuse | | | 2.2 | 2 | 10 | | | | | 10 | | 6-9 | | | | | | | | | | | 0.5- 2.5 |
| 7 | Residential Graywater Reuse | | | 14 | 5 | 10 | | | | | 10 | | 6-9 | | | | | | | | | | | 0.5- 2.5 |
| 8 | Industrial Reuse | 200 | 2.2 | | 2 | 30 | | | | 30 | | | 6-9 | | | | | | | | | | 1 | |
| 9 | Restricted Contact Impoundments | 200 | 2.2 | | | 30 | | | | 30 | | | | | | | | | | | | | 1 | |
| 10 | Non-Food Crop Irrigation Water | 200 | 23 | | | 30 | | | | 30 | | | 6-9 | | | | | 0.1 | | | | | 1 | |
| 11 | Restricted Contact Municipal Reuse | 200 | 23 | | | 30 | | | | 30 | | | 6-9 | | | | | | | | | | 1 | |
| 12 | Processed Food Crop Irrigation Water | 200 | | | | 30 | | | | 30 | | | 6-9 | | | | | 0.1 | | | | | 1 | |
| 13 | Environmental Reuse | 200 | | | | 30 | | | | 30 | | | | | | | | | | | | | 1 | |
| 14 | Secondary Treated Wastewater | | | | | 6.9-13 | | | 1.2 | 5.1-5.7 | | | 7.2-7.9 | | | | | | | | | | 0.5 | |
| 15 | Agricultural Irrigation Water | | | | | | $2x10^3$ | 9 | | | | | 6.5-8.4 | | | | 5-30 | 0.1 | | | | | | |
| 16 | Livestock Drinking Water | | | | | | | $1x10^3$ | | | | | | | | | 100 | 0.2 | | | | | | |
| 17 | Captured Rainwater for Indoor Use | | | 100 | 10 | | | | | | | | | | | | | | | | | | | |
| 18 | Captured Rainwater for Outdoor Use | | | | | | | | | | | | | | | | | | | | | | | |
| 19 | Graywater from Clothes Washing | $50–1.4×10^3$ | $200.5–7×10^5$ | | 50–444 | 68–465 | | | | 48–472 | $231\text{-}2.9x10^3$ | | 7.1–10 | | | 1–40 | | | | | | | | |
| 20 | Graywater from Bathroom Sink & Shower | $0–3.4×10^5$ | $10–2.4×10^7$ | | 44–375 | 7–505 | | | | 50–300 | 100-633 | | 6.4–8.1 | | | 3–19 | | | | | | | | |
| 21 | Primary Treated Wastewater | $7.14x10^6$ - $1.58x10^7$ | | $2.18x10^6$ - $7.90x10^6$ | 26-55 | 43-75 | | | 16-37 | | | | 6.3-7.2 | | | | | | | | | | | |
| 22 | Raw Sewage | $1x10^4\text{-}1.73x10^8$ | | $1.0x10^4\text{-}8.16x10^7$ | | $22\text{-}1.69x10^3$ | | | 35-738 | | $112\text{-}1.1x10^3$ | 10-109 | 6.4-10.1 | | | 20-85 | 0.2-8.5 | | | | | | | |
| 23 | Brackish Water | | | | | | $1x10^3\text{-}3.5x10^4$ | | | | | | | | | | | | | | | | | |
| 24 | Seawater | | | | | | $3.5x10^4$ | $1.1x10^4$ | | | | | 7.4-9.6 | | | | | 0.003 | | | | | | |
| 25 | Conventional Oil Produced Water | | | | | | $80\text{-}4.72x10^5$ | $1.2x10^5$ | | | | 0.565 | 4.3-10 | | | | | | | | | | | |
| 26 | Urban Stormwater | | | | | $0.11\text{-}4.8x10^3$ | | | | | | $0.060\text{-}2.9x10^3$ | 3.4-10.7 | | | | | | | | | | | |
| A | Raw Groundwater - Paso Robles Groundwater Basin | | | | | | 344-762 | | | | | 7-8.2 | | 2.8-18 | 1.4-8 | | 0.04-3.9 | 1.4-17.7 | 0.1-1.3 | | | | | |
| B | Raw Surface Water - Salinas River | $7\text{-}5x10^3$ | $21\text{-}8x10^3$ | 10-460 | 0-359 | 0.8-64 | 290-980 | | | | | 7.3-8.5 | | | | 0.13-2.12 | 0.02-0.56 | | | | | | | |
| C | Raw Precipitation | | | | | | | | | | | | | | | | | | | | | | | |
| D | Water Storage Tanks/Facilities | | | | 0–0.12 | | 120-660 | 10-150 | | | | 7.2-8.1 | | 0-11 | 0-4.5 | | 0-3.9 | 0-0.0064 | | | | | | 0.5-2.4 |
| E | Groundwater Wells Pumping Salinas River Underflow | | | | 1.2 | | 540 | 87 | | | | 7 | | 0 | 0.9 | | 0 | 0 | 0 | 0 | 0 | | | |
| F | Lake Nacimiento (untreated lake water) | | 370-400 | 1 | 2-14 | | 160 | 7.8 | 3.9-4.8 | | | 7-8.6 | | | | | 0.4 | 0.001 | 0.0005 | | | | | |
| G | Nacimiento Water Project Water (delivered) | | $25\text{-}2.4x10^4$ | 0-1 | 3.1-45 | | 100-380 | 7.4-10 | 3.0-4.3 | | | 7.4-8.6 | | 0 | | | 0-0.146 | 0-5.9 | | | | | | |
| H | Raw Untreated Sewage | | | | | $58\text{-}1x10^3$ | $888\text{-}1.1x10^3$ | 151-199 | | 185-530 | | 3-8.7 | | | | | | | | | | | | |
| I | Reclaimed Water | | 1.8-110 | | | 1-14.3 | $737\text{-}1.5x10^3$ | 145-221 | | 2.13-8.9 | | 7.0-8.0 | 2.17-8.9 | | | 0.5-877 | 3.8-4.7 | | | | | | 0.01-0.31 | |
| J | Urban Stormwater Runoff | | | | | | | | | | | | | | | | | | | | | | | |

MCL
Avg.
Min.

Figure 8. Example of Scale of Water Quality in Use: City of Paso Robles, California. Local water quality data inserted into categories A-J. The values on the scale that represent a Maximum Contaminant Level (MCL) are highlighted red. Average values are highlighted orange. Values intended to be a minimum allowable level are highlighted in yellow.

| | | Water Quality Parameters | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Bacteriological | | | Physical | | | | Chemical | | | | | | | | | | | | | | Disinfectants | |
| | | | | | | | Salinity | | Oxyen Demand | | | | | Principal Contaminants in California | | | | | | | | | | |
| | | | | | | | | | | | | | | Radiological | | Inorganic Chemicals | | | | Organic Chemicals | | | | |
| | Categories of Water Quality | Fecal Coliform (CFU/100ml) | Total Coliform (CFU/100ml) | *E. coli* (CFU/100 ml) | Turbidity (NTU) | TSS (mg/L) | TDS (mg/L) | Sodium (mg/L) | TOC (mg/L) | BOD (mg/L) | CBOD (mg/L) | Oil & Grease (mg/L) | pH | Gross Alpha Particle Activity (pCi/L) | Uranium (pCi/L) | Total Nitrogen (mg/L) | Nitrate as Nitrogen (mg/L) | Arsenic (mg/L) | Perchlorate (mg/L) | PCE (mg/L) | TCE (mg/L) | DBCP (mg/L) | Chlorine Residual (mg/L) | Total Chlorine (mg/L) |
| D | Water Storage Tanks/Facilities | | | | 0–0.12 | | 120-660 | 10-150 | | | | 7.2-8.1 | | 0-11 | 0-4.5 | | 0-3.9 | 0-0.0064 | | | | | | 0.5-2.4 |
| 1 | Potable Drinking Water | 0 | | 0 | 1 | | 1x10$^{3}$ | | | | | | 6.5-8.5 | 15 | 20 | | 10 | 0.01 | 0.006 | 0.005 | 0.005 | 0.0002 | 0.2 4 | |
| E | Groundwater Wells Pumping Salinas River Underflow | | | | 1.2 | | 540 | 87 | | | | 7 | | 0 | 0.9 | | 0 | 0 | 0 | 0 | 0 | | | |
| 2 | Potable Surface Water & Groundwater Augmentation | | 2.2 | | 2 | | | | 0.5 | | | | 6.5-8.5 | | | 10 | | | | | | | 1 | |
| 3 | Tertiary Treated Wastewater | | | | | 0.9 | | | 3-3.1 | 2.2-2.6 | | | 7.1-7.4 | | | | | | | | | | 2.7-3.4 | |
| 4 | Food Crop Irrigation Water | 0 | 2.2 | | 2 | | | | | 10 | | | 6-9 | | | | | 0.1 | | | | | 1 | |
| 5 | Public Park Irrigation Water & Recreational Impoundments | 0 | 2.2 | | 2 | | | | | 10 | | | 6-9 | | | | | | | | | | 1 | |
| 6 | Commercial Graywater Reuse | | | 2.2 | 2 | 10 | | | | | 10 | | 6-9 | | | | | | | | | | | 0.5- 2.5 |
| 7 | Residential Graywater Reuse | | | 14 | 5 | 10 | | | | | 10 | | 6-9 | | | | | | | | | | | 0.5- 2.5 |
| 8 | Industrial Reuse | 200 | 2.2 | | 2 | 30 | | | | 30 | | | 6-9 | | | | | | | | | | 1 | |
| 9 | Restricted Contact Impoundments | 200 | 2.2 | | | 30 | | | | 30 | | | | | | | | | | | | | 1 | |
| 10 | Non-Food Crop Irrigation Water | 200 | 23 | | | 30 | | | | 30 | | | 6-9 | | | | | 0.1 | | | | | 1 | |
| 11 | Restricted Contact Municipal Reuse | 200 | 23 | | | 30 | | | | 30 | | | 6-9 | | | | | | | | | | 1 | |
| 12 | Processed Food Crop Irrigation Water | 200 | | | | 30 | | | | 30 | | | 6-9 | | | | | 0.1 | | | | | 1 | |
| 13 | Environmental Reuse | 200 | | | | 30 | | | | 30 | | | | | | | | | | | | | 1 | |
| 14 | Secondary Treated Wastewater | | | | | 6.9-13 | | | 1.2 | 5.1-5.7 | | | 7.2-7.9 | | | | | | | | | | 0.5 | |
| I | Reclaimed Water | | 1.8-110 | | | 1-14.3 | 737-1.5x10$^{3}$ | 145-221 | | 2.13-8.9 | | 7.0-8.0 | 2.17-8.9 | | | 0.5-877 | 3.8-4.7 | | | | | | 0.01-0.31 | |
| F | Lake Nacimiento (untreated lake water) | | 370-400 | 1 | 2-14 | | 160 | 7.8 | 3.9-4.8 | | | 7-8.6 | | | | | 0.4 | 0.001 | 0.0005 | | | | | |
| 15 | Agricultural Irrigation Water | | | | | | 2x10$^{3}$ | 9 | | | | | 6.5-8.4 | | | | 5-30 | 0.1 | | | | | | |
| 16 | Livestock Drinking Water | | | | | | | 1x10$^{3}$ | | | | | | | | | 100 | 0.2 | | | | | | |
| 17 | Captured Rainwater for Indoor Use | | | 100 | 10 | | | | | | | | | | | | | | | | | | | |
| C | Raw Precipitation | | | | | | | | | | | | | | | | | | | | | | | |
| 18 | Captured Rainwater for Outdoor Use | | | | | | | | | | | | | | | | | | | | | | | |
| G | Nacimiento Water Project Water (delivered) | | 25-2.4x10$^{4}$ | 0-1 | 3.1-45 | | 100-380 | 7.4-10 | 3.0-4.3 | | | 7.4-8.6 | | 0 | | | 0-0.146 | 0-5.9 | | | | | | |
| B | Raw Surface Water - Salinas River | 7-5x10$^{3}$ | 21-8x10$^{3}$ | 10-460 | 0-359 | 0.8-64 | 290-980 | | | | | 7.3-8.5 | | | | 0.13-2.12 | 0.02-0.56 | | | | | | | |
| A | Raw Groundwater - Paso Robles Groundwater Basin | | | | | | 344-762 | | | | | 7-8.2 | | 2.8-18 | 1.4-8 | | 0.04-3.9 | 1.4-17.7 | 0.1-1.3 | | | | | |
| 19 | Graywater from Clothes Washing | 50–1.4×10$^{3}$ | 200.5–7×10$^{5}$ | | 50–444 | 68–465 | | | | 48–472 | 231-2.9x10$^{3}$ | | 7.1–10 | | | 1–40 | | | | | | | | |
| 20 | Graywater from Bathroom Sink & Shower | 0–3.4×10$^{5}$ | 10–2.4×10$^{7}$ | | 44–375 | 7–505 | | | | 50–300 | 100-633 | | 6.4–8.1 | | | 3–19 | | | | | | | | |
| 21 | Primary Treated Wastewater | 7.14x10$^{6}$ - 1.58x10$^{7}$ | | 2.18x10$^{6}$ - 7.90x10$^{6}$ | 26-55 | 43-75 | | | 16-37 | | | | 6.3-7.2 | | | | | | | | | | | |
| H | Raw Untreated Sewage | | | | | 58-1x10$^{3}$ | 888-1.1x10$^{3}$ | 151-199 | | 185-530 | | 3-8.7 | | | | | | | | | | | | |
| 22 | Raw Sewage | 1x10$^{4}$-1.73x10$^{8}$ | | 1.0x10$^{4}$-8.16x10$^{7}$ | | 22-1.69x10$^{3}$ | | | 35-738 | | 112-1.1x10$^{3}$ | 10-109 | 6.4-10.1 | | | 20-85 | 0.2-8.5 | | | | | | | |
| 23 | Brackish Water | | | | | | 1x10$^{3}$-3.5x10$^{4}$ | | | | | | | | | | | | | | | | | |
| 24 | Seawater | | | | | | 3.5x10$^{4}$ | 1.1x10$^{4}$ | | | | | 7.4-9.6 | | | | | 0.003 | | | | | | |
| 25 | Conventional Oil Produced Water | | | | | | 80-4.72x10$^{5}$ | 1.2x10$^{5}$ | | | | 0.565 | 4.3-10 | | | | | | | | | | | |
| 26 | Urban Stormwater | | | | | 0.11-4.8x10$^{3}$ | | | | | | 0.060-2.9x10$^{3}$ | 3.4-10.7 | | | | | | | | | | | |
| J | Urban Stormwater Runoff | | | | | | | | | | | | | | | | | | | | | | | |

MCL
Avg.
Min.

Figure 9. Example of Scale of Water Quality in Use: City of Paso Robles, California. Water quality categories A-J are inserted among categories 1-26 for comparison. The values on the scale that represent a Maximum Contaminant Level (MCL) are highlighted red. Average values are highlighted orange. Values intended to be a minimum allowable level are highlighted in yellow.

2. *Wells that extract Salinas River underflow*. The city has surface water rights to the water in the Salinas River. That water is extracted from the Salinas River through the use of wells. The water quality parameter data for this water is inserted into category E (SWRCB 2019b).
3. *Water from Lake Nacimiento*. Paso Robles holds a delivery entitlement for Lake Nacimiento water. For comparison purposes, water quality parameter data for both the untreated surface water (San Luis Obispo County 2019) and the treated, delivered Nacimiento Water Project water (San Luis Obispo County 2018) are inserted into categories F and G, respectively, in Figure 8.
4. *Reclaimed water.* The city has built a new tertiary treatment facility that treats wastewater to reclaim water. The distribution system, still under construction, is expected to be completed in 2021. Until the distribution system is ready to be used, the tertiary treated water is being discharged into the Salinas River. For comparison purposes, water quality parameter data for both the raw untreated sewage entering the wastewater treatment facility (obtained by request from the city of Paso Robles) and the reclaimed water leaving the wastewater and tertiary treatment plant (SWRCB 2019c) are inserted into categories H and I, respectively, in Figure 8.
5. *Urban stormwater runoff.* The rainwater that infiltrates the ground after coming into contact with urban areas is accounted for in category J of Figure 8. The city of Paso Robles has constructed facilities that infiltrate rainwater into the ground; however, because infiltration occurs quickly, the city does not collect water quality data. Since water quality parameter data is not available, category J remains blank and acts as a placeholder for the quantity of urban stormwater runoff so that it can be compared to other categories of water in Figure 9.

Figure 8 lists at the bottom of the scale, in categories A through J, the types of water found in the local environment, as well as other sources of water available to the city of Paso Robles, and the associated water quality parameter data.

*2.1.3 Comparison of the Quality of Water in Paso Robles to the Quality Required for Use*

In order to evaluate how the quality of the available water compares with use requirements, categories A through J are moved up and inserted between the appropriate numbered categories, as explained above and shown in Table 4.

Figure 9 shows the resulting locally-specific scale for Paso Robles' water resources captured in one image, with the quality of water available compared to the standards for use. It puts an additional tool in the hands of the decision makers responsible for resource planning and provides a single focus for communication among multi-disciplinary boards or committees.

## 3. Measure the Quantity and Quality of the Local Water Supply Simultaneously

Developing a water quality scale is an initial step toward adding water quality to a water budget. By adding quantities in volumetric units, the scale can be used to track changes in both quantity and quality as water is extracted, used, collected, and treated, for example.

Figure 10 demonstrates this concept using the scale specific to Paso Robles and the quantities of water used by the city in water year 2014 (Paso Robles 2016). Tracing the change in quality as used water is collected as raw sewage, treated to secondary effluent quality, and discharged into the Salinas River highlights the opportunity to repurpose the secondary treated effluent rather than disposing of it in the Salinas River.

Water year 2014 is depicted here because, by 2015, Paso Robles' wastewater treatment plant was upgraded, and a reclaimed water plant and distribution system for reusing the water discharged into the Salinas River for non-potable water uses, such as irrigation, were in the planning and design

Table 4. Explanation of Scale Order for Paso Robles Water Quality Categories

| | Water in Paso Robles | Explanation for Position on Scale |
|---|---|---|
| **D** | Water Storage Tanks/Facilities | Category D is placed above category 1 because the water quality parameter values available for comparison meet the potable drinking water standards listed in category 1. |
| **E** | Groundwater Wells Pumping Salinas River Underflow | Category E is placed below category 1 because Turbidity (1.2 NTU) exceeds the max of 1 NTU for potable drinking water. |
| **I** | Reclaimed Water | Category I is placed below category 14 because the expected chlorine residual (0.01-0.31 mg/L) is lower than 0.5mg/L. The categories that follow are not be expected to have chlorine residual. |
| **F** | Lake Nacimiento (untreated lake water) | Category F follows category I because Total Coliform (370-400 CFU/100ml) is higher than 1.8-110 CFU/100ml and there is no chlorine residual expected in lake water. |
| **C** | Raw Precipitation | Since Paso Robles does not currently measure rainwater quality, there are no water quality values to compare to the other categories. Category C is placed between categories 17 and 18 (Captures Rainwater) as a placeholder for when values are available. |
| **G** | Nacimiento Water Project Water (delivered) | While category G has higher Total Coliform than category B, category B has higher *E. coli*, by a higher order of magnitude, so category G is placed above category B. |
| **B** | Raw Surface Water - Salinas River | |
| **A** | Raw Groundwater - Paso Robles Groundwater Basin | Category A does not have bacteriological parameter values to compare, but the Arsenic levels are higher than category G, and the Nitrate as Nitrogen level are higher than both G and B, so category A is placed after B. |
| **H** | Raw Untreated Sewage | There are no bacteriological parameter values available to compare, so Category H is placed above category 22 because the upper end of the range of TSS (1,001 mg/L) is less than category 22 (1,690mg/L). |
| **J** | Urban Stormwater Runoff | Paso Robles does not currently measure urban stormwater runoff quality. Since there are no water quality values to compare to other categories, category J is placed below category 26 as a placeholder until Paso Robles has water quality data for this category. |

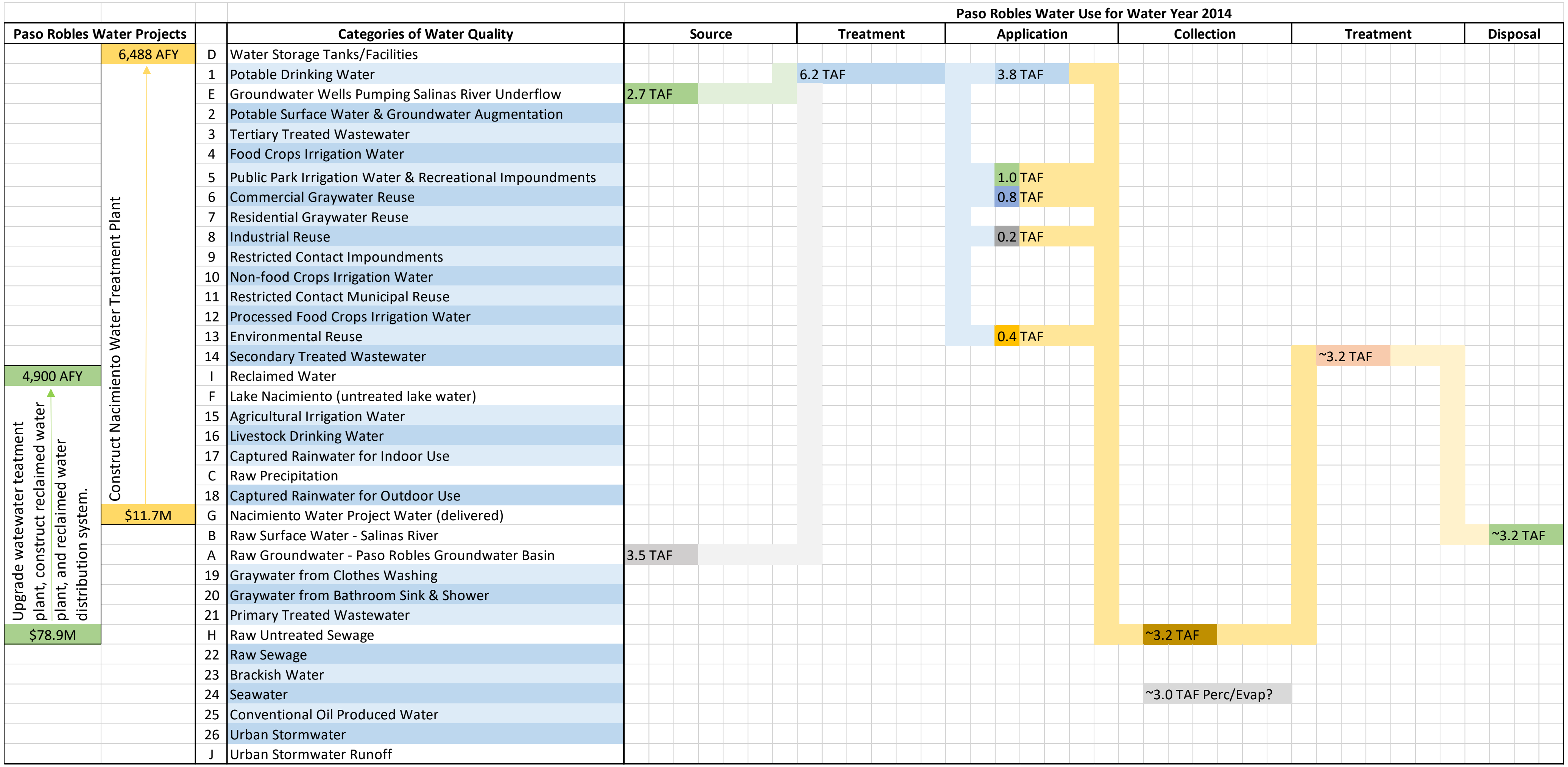


Figure 10. Examples of Paso Robles-Specific Scale of Water Quality Applications. Water use quantity and quality for Water Year 2014 (Paso Robles 2016) is tracked on the right side of the scale. Costs, and volume of water per year to be gained, of moving water from one level of quality to another depicted to the left of the scale (Sneed 2015).

phases. The scale can also be used to depict the cost of moving water from one level of quality to another, as described in the following section.

**4. Communicate the Sustainability of the Water Supply Options Available**

A water quality scale also permits the examination of the impacts (cost, energy use, $CO_2$ emissions) of moving water from one category of water quality to another. Water resource engineers can use the scale to communicate to decision makers the options available for treating the water supply at one water quality category level on the scale to move it to the water quality category level required for a given use and help them select the most sustainable method for increasing the water supply effectively.

Figure 10 demonstrates this concept briefly by using the scale specific to Paso Robles and the costs, along with the potential water produced per year, of the technology options they decided to implement (Sneed 2015). Additional columns could be included to compare the technologies selected to other options available. Energy use or $CO_2$ emissions could also be included depending upon what type of information is important to decision makers.

**5. Examine Water Quality Anywhere in the World**

The scale can also be used as a starting point for a scale specific to another location. To customize the scale for another state or country, replace the state of California data sources (see Figures 5 and 6) with water quality limits specific to the preferred state or country. In the absence of state or country-specific data, the data in this scale can be used. However, California defines graywater differently than some other locations do. For instance, California does not include wastewater from kitchen sinks or dishwashers in its definition of graywater (HSC 2019). If the location for which the scale is being customized includes kitchen wastewater in their definition of graywater, the title, definition, and values listed for water quality category 20 should be modified to include kitchen sink and dishwasher wastewater.

## Summary and Conclusions

Water availability analysis has traditionally involved understanding how much water enters and leaves a region and how much is used or stored each year. This mass balance of water, or water budget, is useful for tracking *quantities* of water; however, it offers no insights into the *quality* of the water. By not including quality, the water budget tells only half the story. It communicates how much water is available and from what sources but not what water sources require treatment before use and which ones can be used at their existing levels of quality. To add water quality to the quantities of water in a water budget, it is necessary to define varying levels of water quality, for example, via a scale of water quality.

This paper introduces a method for creating a water quality scale that defines unique categories for water quality, with additional categories reserved for the insertion of local water quality. The methodology is tested using California as a case study. The data driven, yet subjective, nature of the methodology will allow water resource engineers to tailor the water quality scale to the needs and concerns of local communities and decision makers.

The method and resulting water quality scale can be used by water resource engineers to compare different types of water in terms of quality, measure the quantity and quality of a local water supply simultaneously, and communicate the most sustainable water supply options available. Furthermore, the scale is customizable for use anywhere in the world.

## Acknowledgments

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## Data Statement

All data, models, and code generated or used during the study appear in the submitted article.

## Supplemental Materials

The templates used to create Figures 5-7, are supplemental materials Figures S1-S3, and are available online in the ASCE Library (www.ascelibrary.org).

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